



ELECTRICAL ENGINEERING TECHNICAL NOTE

COPPER BUSBAR SIZING

1,600 A Transformer Secondary — 2,000 kVA

Full design calculation | Cross-section selection | Short-circuit verification | 40°C ambient

Document No.	ETN-BUS-001 Rev. A	Standard	IEC 60439 / NEC
Subject	Busbar sizing & SC check	Ambient Temp.	40°C

1. SCOPE & DESIGN PARAMETERS

This technical note sizes a copper busbar system for the 415 V secondary terminals of a 2,000 kVA, 11 kV/415 V oil-immersed distribution transformer. The busbar must carry 1,600 A continuous current, withstand the prospective short-circuit current at the secondary bus, and operate safely in a 40°C ambient environment inside a switchboard enclosure.

1.1 Input Data Summary

Parameter	Symbol	Value	Unit / Reference
Transformer rated power	S	2,000	kVA
Secondary rated voltage (L-L)	V ₂	415	V (3-phase, 50 Hz)
Power factor (design)	cos φ	0.85	lagging
Busbar rated current	I _{rated}	1,600	A (design target)
Ambient temperature	θ _a	40	°C
Max allowable conductor rise	Δθ	50	°C (IEC 60439-1)
Max conductor temperature	θ _{max}	90	°C
Short-circuit duration	t _{sc}	1.0	s
Transformer impedance	Z _T %	5.75	% (typical IEC value)
Conductor material	—	Copper (ETP)	Grade C11000

Parameter	Symbol	Value	Unit / Reference
Busbar mounting	—	Horizontal, edge-on	3 phases, flat bars
Enclosure	—	IP31 switchboard	—

⚡ KEY STANDARD REFERENCES

- IEC 60439-1 / IEC 61439-1 — Low-voltage switchgear and controlgear assemblies
- IEC 60865-1 — Short-circuit currents: calculation of effects (mechanical & thermal)
- AS/NZS 3000:2018 / NEC Article 366 — Busway sizing requirements
- BS 159 / EN 13601 — Copper and copper alloy bar stock

2. FULL-LOAD CURRENT VERIFICATION

2.1 Transformer Secondary Full-Load Current

The rated full-load current at the transformer secondary terminals is derived from the apparent power rating and the line-to-line voltage for a balanced three-phase system:

Formula: $I_{FL} = S / (\sqrt{3} \times V_2)$

$I_{FL} = 2,000,000 / (1.7321 \times 415)$

Result: $I_{FL} = 2,000,000 / 718.8 \rightarrow = 2,783 \text{ A}$

⚠ Note: The 2,000 kVA transformer full-load current (2,783 A) exceeds our 1,600 A busbar design. This is intentional — the busbar feeds a sub-section of the switchboard (e.g., main feeder panel feeding downstream at 1,600 A maximum demand). The busbar must be rated for its actual maximum demand, not necessarily the full transformer output.

2.2 Design Current for the Busbar Run

The busbar is sized for the specific circuit maximum demand. Using a demand factor of 0.575 on the transformer KVA:

Design current: $I_{design} = 1,600 \text{ A} \rightarrow$ (given — circuit maximum demand)

Diversity factor: $DF = I_{design} / I_{FL} \rightarrow = 1,600 / 2,783 = 0.575 \checkmark$

Design Load Current	1,600	A <i>continuous</i>
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3. AMBIENT TEMPERATURE DERATING

3.1 Derating Factor Calculation

Standard busbar current-carrying capacity tables are typically published for 35°C or 40°C ambient with a 50°C conductor temperature rise (giving 85°C max). Since our ambient is 40°C and maximum conductor temperature is 90°C, we verify the derating factor:

$$\theta_{max} = \theta_{ambient} + \Delta\theta = 40 + 50 \rightarrow = 90^{\circ}\text{C} \quad \checkmark \quad (\text{within copper limit of } 105^{\circ}\text{C})$$

Derating factor relative to 35°C base tables:

$$k_{temp} = \sqrt{[(\theta_{max} - \theta_a) / (\theta_{max} - \theta_{base})]}$$

$$k_{temp} = \sqrt{[(90 - 40) / (90 - 35)]} = \sqrt{[50/55]} \rightarrow = \sqrt{0.9091} = 0.9535$$

Derating Factor (40°C vs 35°C baseline): $k_{temp} = 0.954$

The required busbar ampacity must be divided by this factor when selecting from 35°C tables,
OR the 40°C-rated table value is used directly (preferred — no additional correction needed).

3.2 Required Busbar Ampacity

We will use manufacturer/standard tables published for 40°C ambient directly. The target current-carrying capacity:

$$I_{required} = I_{design} / k_{mounting}$$

$k_{mounting}$ (edge-on, 3-ph flat): $\approx 0.95 \rightarrow$ (IEC correction for grouped flat bars)

$$I_{required} = 1,600 / 0.95 \rightarrow = 1,684 \text{ A} \quad (\text{ampacity to select from tables})$$

Required Ampacity from Tables	$\geq 1,684$	A at 40°C
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4. CROSS-SECTION SELECTION

4.1 Candidate Cross-Sections — Standard Copper Flat Bar

Copper flat bars (ETP Cu, conductivity 100% IACS = 58 MS/m) are evaluated. Current-carrying capacities are per IEC 60439-1 Annex A for horizontal, edge-mounted bars in still air at 40°C, 50°C rise:

Bar Size (mm)	Cross-section (mm ²)	Ampacity 40°C (A)	Resistance (μΩ/m)	Mass (kg/m)	Status
80 × 8	640	1,350	27.1	5.69	X Under-rated
100 × 8	800	1,590	21.6	7.12	X Marginal
100 × 10	1,000	1,850	17.3	8.90	✓ SELECTED
120 × 10	1,200	2,100	14.4	10.68	✓ Conservative

Bar Size (mm)	Cross-section (mm ²)	Ampacity 40°C (A)	Resistance (μΩ/m)	Mass (kg/m)	Status
2× 60 × 8	960	1,750*	22.5	8.54	✓ Alternate

* Laminated (twin bar) ampacity corrected: single-bar × 1.75 factor for intimate contact twin bars.

4.2 Selected Section: 100 mm × 10 mm Copper Flat Bar

SELECTED BUSBAR: 100 mm × 10 mm Copper (ETP C11000) — ONE bar per phase

Cross-sectional area: A = 1,000 mm² | Rated ampacity: 1,850 A at 40°C

Ampacity margin: (1,850 – 1,684) / 1,684 × 100 = +9.9% ✓ Adequate margin

4.3 Current Density Check

Current density is verified against the guideline of 1.6–2.5 A/mm² for copper busbars in switchboard applications:

$$J = I_{\text{design}} / A = 1,600 / 1,000 \rightarrow = 1.60 \text{ A/mm}^2 \quad \checkmark$$

Current Density	1.60	A/mm ² ✓ (within 1.6–2.5 guideline)
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4.4 Resistance and Voltage Drop

DC resistance at 20°C for 100×10 Cu bar:

$$R_{\text{dc}} = \rho / A = (1/58 \times 10^6) / (1,000 \times 10^{-6}) \rightarrow = 17.24 \text{ } \mu\Omega/\text{m}$$

$$R \text{ at } 90^\circ\text{C}: R_{90} = R_{20} \times [1 + \alpha(90-20)] \rightarrow = 17.24 \times [1 + 0.00393 \times 70] = 22.0 \text{ } \mu\Omega/\text{m}$$

AC resistance (skin effect correction factor k_s ≈ 1.02 for 10 mm thin bar at 50 Hz):

$$R_{\text{ac}} = R_{90} \times k_s = 22.0 \times 1.02 \rightarrow = 22.4 \text{ } \mu\Omega/\text{m}$$

Voltage drop per metre (three-phase):

$$\Delta V = \sqrt{3} \times I \times R_{\text{ac}} \times L \quad (L = \text{busbar run length})$$

$$\Delta V \text{ per metre: } = 1.732 \times 1,600 \times 22.4 \times 10^{-6} \rightarrow = 62.1 \text{ mV/m}$$

For a 10 m busbar run: ΔV = 0.621 V → ΔV% = 0.621/415 × 100 = 0.15% ✓ (well within 1% limit)

5. SHORT-CIRCUIT CURRENT VERIFICATION

5.1 Prospective Short-Circuit Current at Secondary Terminals

The maximum symmetrical short-circuit current at the 415 V bus is determined by the transformer impedance alone (upstream grid impedance conservatively neglected — worst case for the busbar):

$$\begin{aligned}
 I_{sc(sym)} &= I_{FL_transformer} / (Z_T\% / 100) \\
 I_{FL_transformer} &= 2,000,000 / (\sqrt{3} \times 415) \rightarrow = 2,783 \text{ A} \\
 I_{sc(sym)} &= 2,783 / 0.0575 \rightarrow = 48,400 \text{ A} \quad (48.4 \text{ kA rms})
 \end{aligned}$$

5.2 Peak Short-Circuit Current (Making Current)

The peak (asymmetric crest) current is needed for electromagnetic force calculations. Using IEC 60909 peak factor $\kappa = 1.02 + 0.98 \times e^{(-3R/X)}$ with $X/R \approx 10$ for distribution transformers:

$$\begin{aligned}
 R/X = 1/10 = 0.1 \quad \kappa &= 1.02 + 0.98 \times e^{(-3 \times 0.1)} \rightarrow = 1.02 + 0.98 \times e^{(-0.3)} \\
 \kappa &= 1.02 + 0.98 \times 0.7408 \rightarrow = 1.02 + 0.726 = 1.746 \\
 I_{peak} &= \kappa \times \sqrt{2} \times I_{sc(sym)} = 1.746 \times 1.4142 \times 48,400 \rightarrow = 119.5 \text{ kA peak}
 \end{aligned}$$

Symmetrical SC Current	48.4 kA	<i>rms — at 415 V bus</i>
Peak (Asymmetric) SC Current	119.5 kA	<i>peak — IEC 60909</i>

5.3 Thermal Withstand Verification

The adiabatic heating of the busbar during a 1-second fault is checked using the Joule integral (I^2t) method per IEC 60865-1. The temperature rise above initial operating temperature must keep conductor below 200°C (IEC short-time maximum for copper):

Thermal limit formula: $A_{min} = I_{sc} \times \sqrt{t} / K$

Where K is the material constant for copper (initial temp 90°C, final limit 200°C):

$$\begin{aligned}
 K_{cu} &= 226 \text{ A} \cdot \text{s}^{0.5} / \text{mm}^2 \quad (\text{IEC 60364-5-54, copper } 90 \rightarrow 200^\circ\text{C}) \\
 A_{min} &= 48,400 \times \sqrt{1.0} / 226 = 48,400 / 226 \rightarrow = 214.2 \text{ mm}^2 \\
 \text{Actual area } A &= 1,000 \text{ mm}^2 \rightarrow \gg 214.2 \text{ mm}^2 \quad \checkmark\checkmark \\
 \text{Thermal margin} &= 1,000 / 214.2 \rightarrow = 4.67 \times \quad (367\% \text{ margin})
 \end{aligned}$$

Thermal SC Withstand	PASS	<i>Margin: 4.67× (367%)</i>
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5.4 Electromagnetic Force Verification

Busbars carrying high fault currents experience mechanical forces between parallel conductors. The peak force per unit length between adjacent phases (worst case, spacing $s = 150 \text{ mm}$ centre-to-centre):

$$\begin{aligned}
 F/L &= \mu_0 / (2\pi) \times I_{peak}^2 / s \\
 &= (4\pi \times 10^{-7}) / (2\pi) \times (119,500)^2 / 0.15 \\
 &= 2 \times 10^{-7} \times 14,280,250,000 / 0.15
 \end{aligned}$$

$$F/L = = 19,040 \text{ N/m} \rightarrow \approx 19.0 \text{ kN/m (peak, first half-cycle)}$$

For a busbar supported at 600 mm (0.6 m) span intervals, the maximum bending moment on a simply-supported beam:

$$M_{\text{max}} = F/L \times L_{\text{span}}^2 / 8 = 19,040 \times 0.6^2 / 8 \rightarrow = 19,040 \times 0.045 = 856.8 \text{ N}\cdot\text{m}$$

$$\text{Section modulus } W: = b \times h^2 / 6 = 0.01 \times 0.1^2 / 6 \rightarrow = 1.667 \times 10^{-5} \text{ m}^3$$

$$\text{Bending stress: } \sigma = M/W = 856.8 / 1.667 \times 10^{-5} \rightarrow = 51.4 \text{ MPa}$$

$$\text{Copper yield strength: } \sigma_y \geq 200 \text{ MPa (annealed Cu)} \rightarrow 51.4 < 200 \text{ MPa} \checkmark$$

Mechanical SC Withstand	PASS	$\sigma = 51.4$ $\text{MPa} <$ $\sigma_y = 200$ MPa
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6. DESIGN SUMMARY

6.1 Final Selection

Criterion	Required	Provided	Margin	Status
Continuous ampacity	1,684 A	1,850 A	+9.9%	✓ PASS
Current density	≤ 2.5 A/mm ²	1.60 A/mm ²	36% headroom	✓ PASS
Max conductor temp.	≤ 90°C	90°C	At limit (design)	✓ PASS
Voltage drop (10 m run)	≤ 1%	0.15%	85% headroom	✓ PASS
Thermal SC withstand	214 mm ²	1,000 mm ²	4.67× (367%)	✓ PASS
Mechanical SC stress	≤ 200 MPa	51.4 MPa	74% headroom	✓ PASS

FINAL SPECIFICATION

100 mm × 10 mm Copper Flat Bar (ETP C11000)

1 bar per phase • 1,000 mm² cross-section • 1,850 A rated • SC-rated 48.4 kA / 1 s

Max span: 600 mm • Phase centres: 150 mm • Surface: bare or tin-plated

6.2 Hardware & Installation Notes

Item	Specification
Conductor	Copper flat bar 100×10 mm, ETP Grade C11000, min. 99.9% Cu, hard-drawn
Surface finish	Bare copper or electroplated tin (preferred for connection reliability)

Item	Specification
Insulation	Heat-shrink sleeving (red/yellow/blue per phase) or PVC extrusion, ≥1,000 V rating
Support insulators	DMC/SMC resin, 1,000 V AC rated, rated for 119.5 kA peak electromagnetic force
Support spacing	≤ 600 mm c/c (as designed for mechanical SC withstand)
Phase-to-phase spacing	150 mm c/c (flat, edge-on)
Joining	Bolted with M12 HV-grade bolts, Belleville washers, contact grease. Min 4 bolts per joint
Torque (M12 Cu-Cu)	30–35 N·m, verified with torque wrench
Expansion joint	Required if busbar run > 6 m (copper expansion 17 μm/m·°C)
Protective relay	Overcurrent relay set 1,600 A, instantaneous 50× = 80 kA — coordinate with upstream

7. APPENDIX — COPPER PROPERTIES & FORMULAE

7.1 Copper (ETP C11000) Material Properties

Property	Symbol	Value	Unit
Electrical conductivity (20°C)	σ	58.0	MS/m (100% IACS)
Resistivity (20°C)	ρ_{20}	17.24	nΩ·m
Temperature coefficient	α	0.00393	K ⁻¹ (at 20°C)
Density	ρ_m	8,900	kg/m ³
Melting point	T_melt	1,083	°C
Thermal conductivity	λ	394	W/m·K
Yield strength (annealed)	σ_y	≥ 200	MPa
Yield strength (hard-drawn)	σ_y	≥ 280	MPa
Modulus of elasticity	E	117	GPa
Linear expansion coefficient	α_L	17	μm/m·°C
SC K-factor (90→200°C)	K	226	A·s ^{0.5} /mm ² (IEC 60364-5-54)

7.2 Key Formulae Reference

Full-load current: $I_{FL} = S / (\sqrt{3} \times V_{LL})$

Ampacity derating: $k = \sqrt{[(\theta_{max} - \theta_a) / (\theta_{max} - \theta_{ref})]}$

SC current (sym): $I_{sc} = I_{FL} / Z_{T\%}$

SC peak (IEC 60909): $I_{\text{peak}} = \kappa \times \sqrt{2} \times I_{\text{sc}}$; $\kappa = 1.02 + 0.98 \times e^{(-3R/X)}$

Thermal min. area: $A_{\text{min}} = I_{\text{sc}} \times \sqrt{t} / K$

EM force/length: $F/L = (\mu_0/2\pi) \times I_{\text{peak}}^2 / s$

Bending stress: $\sigma = M/W$; $M = (F/L) \times L^2/8$; $W = b \times h^2/6$

Voltage drop: $\Delta V = \sqrt{3} \times I \times R_{\text{ac}} \times L$

This technical note is for engineering reference only. Results must be verified by a qualified electrical engineer before implementation.

Standards: IEC 60439-1 | IEC 60865-1 | IEC 60909 | IEC 60364-5-54